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CMS LVPS – Summary of water cooling calculations

Here is a summary of the water cooling calculations for the low voltage power supplies.

Estimated heat loads for supplies

1.) ECAL: 48 v @ 30 amps. Assume 10% inefficiency.
    Q = 0.1(48v)(30 A)= 144 watts
2.) HCAL: 3 outputs, 4.8v @ 12 amps + 6.5 v @ 9 amps. Assume worst case 50% inefficiency. Q= 0.4(3 outputs)[(4.8v)(12 A)+(6.5v)(9 A)]= 140 watts
3.) EMU: 7.5 v @ 80 amps & 120 amps. Assume worst case 50% inefficiency. Q = 0.5(7.5v)(80 A + 120 A)= 750 watts.

All three supplies will be similar in design. Therefore a worst case heat load of 750 watts will be used for the calculations.

Assumptions

A.) Water supply: Pressure = 7 bars, Temperature 13 C to 15 C.
B.) Water return: Pressure 3 to 4 bars, Temperature 15.5 to 17.5 C.
C.) Ambient: Temperature = 21 C, Dewpoint = 10 C.

Water flow required
Basic heat transfer equation: Q = mdot * Cp * (Tout – Tin).

Let: Q = 750 watts worst case heat load, (Tout-Tin) = 2.5 C, Cp = 4.2 J/g-K for water

Then: mdot = Q/(Cp*(Tout-Tin)) = (750 J/s)/[4.2 J/g-K*(2.5 K)] = 71 g/s

Mdot, flow rate = 71 g/s = **4.3 lpm = 1.1 gpm per power supply for 2.5 C coolant rise.**

Pressure drop in cooling tube
The current copper cold plate design uses a 9 mm OD x 8mm ID tube with an approximate length of 165 cm (5.4 feet). The bends in the tubing are generous and do not add to the equivalent length. For worst case conditions, I am assuming that 3 power supplies will be connected in series. Therefore a flow of 12.9 lpm = 3.3 gpm will be used.

Pressure drop tables in Crane Technical paper #410, page B-14 were used. The values were scaled. Specifically, for mdot = 3 gpm, and ¼" Sch. 40 (ID = .364 inch), pressure drop = 64.1 psi per 100 feet. The scaling goes to the 5th power for diameter and the square for the flowrate.

DeltaP_2 (ID=8 mm, 3.3 gpm) = $\text{DP}_1 * [\text{ID}_1/\text{ID}_2]^5 * [\text{mdot}_2/\text{mdot}_1]^2$
DeltaP_2 (ID=8 mm, 3.3 gpm) = $(64.1 \text{ psi})*[.364/.315]^5 * [3.3/3.0]^2$ = 160 psi per 100 ft.

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For 3.3 gpm flow, pressure drop = (5.4 ft)(1.6 psi/ft) = 8.6 psi = 0.6 bar for each power supply. **Total pressure drop for the 3 power supplies in series (12.9 lpm flow) = 1.8 bar.**

<u>Heat transfer</u>
This is a check of the heat transfer to confirm the tubing length is adequate.

Reynolds #, Re = 50.6 * [(mdot)*(density)/(ID)*(viscosity)] in appropriate units, reference eqn. 3-3, Crane technical paper 410.

Re = 50.6 [(1.1 gpm)(62.4 lb/ft3)/(.315 inch)(1.2 centipoise)] = 10,000

This is the turbulent flow regime. A convection correlation for turbulent flow in circular tubes is:

Nusselt #, $Nu_D = 0.023 (Re_D)^{0.8} * (Pr)^{n}$

where n = 0.4 for $T_{surface} > Tm$ for heating. Reference Eqn. 8.60, Fundamentals of Heat and Mass Transfer, Incropera and Dewitt, 3rd edition.

For water at 287 K, Prandtl #, Pr = 8.2 from property tables in the above reference. For the tube, L/D = 65 inch/0.315 inch = 200 > > 10. The equation is valid for our conditions of Re#, Pr#, and L/D.

$Nu_D = 0.023 (10{,}000)^{0.8} * (8.2)^{0.4} = 85$

$Nu_D \equiv h D / k$, re-arranging and solving for convection coefficient, $h = Nu_D * k / D$

From property tables, water at 287.5 K, thermal conductivity, k = 0.594 W / m-K

$h = Nu_D * k / D = 85 (0.594 \text{ W/m-K}) / 0.008 \text{ m} = 6280 \text{ W/m}^2\text{-K}$

The internal surface area of the tubing, $A = \pi D L = \pi (0.008 \text{ m})(1.65 \text{ m}) = 0.041 \text{ m}^2$

The temperature difference, cold plate to fluid = (T_s- T_{fluid}) = Q / h*A

$(T_s - T_{fluid}) = (750 \text{ Watts}) / (6280 \text{ W/m}^2\text{-K})(0.041 \text{ m}^2)$ **= 2.9 Kelvin**

This is a pretty low temperature drop, the tubing length could be reduced if the thermal path from the cold plate to the tubing is good. The internal convection coefficient will be a bit better for higher water flow rates.